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The use of CASES-97 observations to assess and parameterize the impact of land-surface heterogeneity on area-average surface heat fluxes for large-scale coupled atmosphere-hydrology models

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1. Project Summary and Background

To understand the effects of land-surface heterogeneity and the interactions between the land-surface and the planetary boundary layer at different scales, we develop a multi-scale data set. This data set, based on the Cooperative Atmosphere-Surface Exchange Study (CASES97) observations, includes atmospheric, surface, and sub-surface observations obtained from a dense observation network covering a large region on the order of 100 km. We use this data set to drive three land-surface models (LSMs) to generate multi-scale (with three resolutions of 1, 5, and 10 km) gridded surface heat flux maps for the CASES area

Upon validating these flux maps with measurements from surface station and aircraft, we utilize them to investigate several approaches for estimating the area-integrated surface heat flux for the CASES97 domain of 71x74 km^2, which is crucial for land-surface model development/validation and area water and energy budget studies. This research is aimed at understanding the relative contribution of random turbulence versus organized mesoscale circulations to the area-integrated surface flux at the scale of 100 km, and identifying the most important effective parameters for characterizing the subgrid-scale variability for large-scale atmosphere-hydrology models.

Furthermore, we study, by using aircraft and profiler measurements at multi levels together with the multi-scale surface flux maps over the CASES-97 domain, the 3-D structure of PBL development and its interactions with the underlying inhomogeneous surface. As such, our analysis is expected to provide insight on the atmosphere-soilhydrology interactions and the effects of subgrid-scale surface variability at scales from 1 km to a large watershed (4800 km^2).

2. Major milestones accomplished

1) Develop a multi-scale gridded data set including atmospheric and surface conditions for the CASES-97 domain

The multi-scale (1, 5, and 10km) gridded atmospheric forcing data are based on four major sources: 1) eight PAM and ASTER surface stations; 2) 1-km S-Pol precipitation analysis and 4-km hourly NEXRAD precipitation analysis; 3) 1-km resolution vegetation and soil maps; and 4) 1-km NDVI data. The above data are used to develop a gridded data set of atmospheric forcing variables with 30-min time interval for the period April 22 1997 00:00 UTC to May 22 1997 23:45 UTC and for the CASES97 domain of 71x74 km^2. For details about this data set, see Yates et al. (2001).

2) Utilize the surface data to validate coupled model simulations

The surface sensible, latent, and ground heat flux in the CASES97 domain are used to validate the coupled MM5 simulations with two land-surface models (OSULSM and HTSVS for 20 May, the last Intensive Observing Period of the experiment. Simulations with MM5 with both LSMs compare well with observations. The main differences are in the partitioning of incoming net radiation among surface heat fluxes. The results are summarized in an article submitted to Journal of Hydrometeorology by Molders et al. (2001)

3) Generate multi-scale surface heat flux maps with LSMs over the CASES domain

To obtain the surface heat flux maps, the multi-scale gridded data set is used to drive three LSMs: 1) OSULSM: a relatively simple vegetation model with four soil layers; 2) SOLVEG: having nine canopy layers and seven soil layers and a treatment of both the water and vapor phase in the soil; and 3) NCARLSM: with six soil layers, CO_2 cycle, and surface heterogeneity representation.

4) Validate the LSM simulations with surface and aircraft flux measurements

The SOLVEG model was verified against the surface heat fluxes measured at nine stations. By using an optional solar radiation scheme with canopy layers, model results agreed well with observations. The vegetation treatment was improved by incorporating the green vegetation fraction in the model. These verification results are described by Nagai (2001)

Further, simulations from three LSMs are intercompared and compared to surface and aircraft measurements. In spite of model differences, all three LSMs reasonably captured the surface heat fluxes measured at nine surface stations located over various landuse types. They also produce the observed average fluxes, as well heterogeneity observed from aircraft. However, there were features in the aircraft data that could not simply be explained by surface properties. Rather, they appear to be related to mesoscale eddies in the atmosphere (Chen et. al. 2001).

5) Scaling analysis of surface heat flux maps

The scaling analysis is conducted with surface heat flux maps at 1, 5, and 10-km simulated by three LSMs. Statistics are computed to investigate the scaling properties of these multi-scale fluxes as they are aggregated into a scale of 71x74 km^2. The accumulated effects of subgrid-scale variability on evaporation and surface energy balance for a one-month period is explored (see Yates at al. 2001 for details)

6) Impact of surface heterogeneity on the development of the convective boundary layer

To understand the impact of subgrid-scale variability on the model simulated convective planetary boundary layer (PBL), we run the PSU/NCAR MM5 model using flux maps as lower boundary conditions at three grid resolutions (1, 5, and 10 km). By coupling the MM5 model with the accurate flux maps in one-way interactive mode, we eliminate the biases in surface heat fluxes caused by atmospheric models so that we can focus on the development of the PBL. One key benefit from the CASES data set is the detailed description of the spatial and temporal structure of the PBL with sounding, aircraft, and profilers observations. During five IOPs, radiosondes were released at 90-minute intervals from the three profiler sites, and aircraft flew straight-and-level legs at multiple levels to obtain fluxes, soundings to estimate boundary-layer depth, and 'triangle' flights connecting the three profiler sites to enable intercomparison and to provide estimates of horizontal gradients. We are verifying the structure simulated by two PBL parameterization schemes (so-called MRF non-local scheme and Mellor-Yamada 2.5 TKE scheme) coupled to the PSU/NCAR MM5 model against these data.

3. New Results and Impacts:

a. Data improvement

We applied interpolation techniques to CASES97 data and collected satellite, gauge-corrected radar-estimated rainfall, land-use and soil data to produce a gridded dataset for the CASES-97 period. Careful examination of the data during this project has led to improvements of the CASES97 surface dataset, originally measured at the surface-tower observation network implemented by Steve Oncley (ATD/NCAR). One important lesson learned from the effort is that the data people and model people need to work together to make high-quality datasets that are suitable for model evaluation and studying surface heterogeneity.

b. Crucial role of soil hydraulic properties and soil moisture stress function in land-surface modeling

Three land-surface models were tested against the CASES97 data set, which provided valuable information on effects of land-use type (e.g., winter wheat, natural grassland, and sparsely vegetated surface) and their growing cycle on surface energy budgets. One interesting result we found in this research effort is that the parameterization soil hydraulic conductivity and soil moisture stress function play a fundamental role in land-surface modeling. Regardless of the complexity of these land-surface models, these two basic parameterizations seem to contribute to the major differences in their surface evaporation and soil moisture evolution.

c. Scaling of surface heterogeneity using aircraft and surface measurements and modeling

The 1x1 km gridded surface sensible and latent heat flux maps for the CASES97 74x72 km^2 area were generated from three land-surface models (OSULSM, SOLVEG, and NCARLSM). They are compared to the heat flux measured by two aircrafts (Wyoming King Air and NOAA Twin Otter) at 30-40 meters. In spite of model differences, three LSMs seem to reasonably capture the variations of heat fluxes along morning flight-tracks. They also produce the observed average fluxes, as well as spatial heterogeneity forced by landuse and soil moisture observed from aircraft. However, there were features in the aircraft data that could not simply be explained by surface properties. Rather, they appear to be related to mesoscale eddies in the atmosphere. These studies demonstrate that a combination of aircraft, surface, remote-sensing measurements, and modeling could provide valuable information about the scaling of surface heterogeneity over difference landuse types and soil moisture and hints of aggregation of surface heat fluxes for regional and global models.

In summary, these studies demonstrate the usefulness and limitation of difference approaches in studying the scaling and aggregation of surface heat fluxes and evaporation over different landuse types. In particular, modeling results are very useful to help the design of aircraft flight tracks and the deployment of surface-tower stations. The longer length of aircraft tracks and more frequent repetition of flight should improve data sampling and help capture the surface heterogeneity, and sampling and leg-average techniques need to be investigated. Furthermore, soil moisture and temperature profiles and measurements of soil hydraulic properties collocated at surface-tower stations with complete atmospheric conditions are critical for land-surface modeling and its verification. Based on these results, we will start a new field experiment, with a better experiment design, in order to enhance the International Water Vapor Project (IHOP) surface-tower and boundary layer measurements, planned for May-June 2002 in the Southern Great Plains region.

4. Meeting Sponsored:

a. A special session on CASES for the AGU Fall Meeting, 15-19, December 2000, San Francisco, CA, was organized by PIs (F. Chen and M. LeMone) and partially supported by this grant.

b. The WRF Land-Surface Modeling Workshop, 16-17, August 2001, Boulder, CO, was organized by PI (F. Chen) and partially supported by this grant.

5. References:

1) Publications in Major Peer-Reviewed Journals:

Yates, D.N, F. Chen, M. LeMone, R. Qualls, S. Oncley, R. Grossman, and E. Brandes, 2001: A CASES dataset for analzing and parameterizing the effects of land-surface heterogeneity on area-averaged surface heat fluxes. *J. Appl. Meteor.*, **40**, 921-937.

Moelders, N., J. Dudhia, F. Chen, and M.A. LeMone, 2000: Comparison and evaluation of OSULSM and HTSVS MM5 for an episode during CASES97. submitted to J. Hydrometeor.

Nagai, Hayuyasu, 2001: An atmosphere-soil-vegetaton model and its validation with observation data and sensitivity analysis. Submitted to *J. Appli. Meteor.*

LeMone, M., R. Grossman, R.T. McMillen, K.N. Liou, S. Oh, S. McKeen, W. Angevine, K. Ikeda, and F. Chen, 2001: CASES-97: Late-morning warming and moistening of the boundary layer over the Walnut River watershed. *Boundary Layer Meterology*, in press.

Chen, F., D. Yates, H. Nagai, M.R., Lemone, R. Grossman, and K. Ikeda, 2001: Modeling the Land-Surface Heterogeneity and Comparison With the CASES-97 Field Observations. Part I: Verification of model simulations. To be submitted to *J. Geophy. Res.*

Yates, D., F. Chen, and H. Nagai, 2001: Modeling the Land-Surface Heterogeneity and Comparison With the CASES-97 Field Observations. Part II: Scaling analysis. To be submitted to *J. Geophy. Res.*

Grossman R., Yates, D., and LeMone M., 2001: Land surface features associated with aircraft observations of variations in surface heating: Evidence of the effects of large eddies on surface fluxes. In Preparation

2) Presentations and Conference Papers

Grossman, R.L, M.A. LeMone, K.-N Liou, and K. Ikeda, 2000: CASES-97 Late-morning moisture and sensible heat budgets over a midwest watershed: CASES97. Proc. 14th Symp. on Boundary Layer and Turbulence, Aspen, 7--11 August, 1--4.

LeMone, M., and R. Grossman, 2000: Mesoscale and diurnal variability of 2-m temperature and mixing ratio in CASES-97. Proc. 14th Symp. on Boundary Layer and Turbulence, Aspen, 7--11 August, 5--8.

Chen, F., D. Yates, M. LeMone, H. Nagai, S.Onkley, and R. Grossman, 2000: A multi-scale data set based on CASES-97 for studying the land-surface heterogeneity and for validating land-surface models. 14th Symp. on Boundary Layer and Turbulence, Aspen, 7--11 August.

Chen, F.,R. Grossman, M.A. LeMone, H. Nagai, and D. Yates: The effects of surface processes on the evolution of the PBL and its potential effect on storm initiation. USWRP Symposium, Boulder, CO.,27--28 March 2000.

Nagai, H., H. Yamazawa, M.A. LeMone, F. Chen, D. Yates, and R.L. Grossman, 2000: Validation, sensitivity analysis, and improvement of atmoshsere-soil-vegetation model by using CASES-97 data. AGU, San Francisco.

Chen, F., D. Yates, H. Nagai, M. LeMone, R. Grossman, K. Ikeda, and L. Berry, 2000: Land-surface heterogeneity in CASES-97: Modeling, in-situ, and aircraft observations. AGU Fall Meeting. 15-19, December, 2000, San Francisco, CA.

LeMone, M.A., and R.L. Grossman, 2000: The impact of larger-scale eddies and surface properties on PBL fluxes over land. AGU Fall Meeting. 15-19, December, 2000, San Francisco, CA.